UNCLASSIFIED

(12)

ARL-STRUC-TECH-MEMO-344

AR-002-899

AD A133009

AUSTRALIA

DEPARTMENT OF DEFENCE SUPPORT

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Structures Technical Memorandum 344

REPORT ON A VISIT TO THE U.S.A. DURING JANUARY 1982 RELATING TO THE EFFECT OF TURBULENCE AND OTHER METEOROLOGICAL HAZARDS ON AIRCRAFT FLIGHT

Douglas J. SHERMAN

Approved for Public Release

DTIC FILE COPY

COPY No

83 09 26 011

AUGUST, 1982

UNCLASSIFIED

AR-002-899

DEPARTMENT OF DEFENCE SUPPORT

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

Structures Technical Memorandum 344

REPORT ON A VISIT TO THE U.S.A. DURING JANUARY 1982 RELATING TO THE EFFECT OF TURBULENCE AND OTHER METEOROLOGICAL HAZARDS ON AIRCRAFT FLIGHT

by

Douglas J. SHERMAN

SUMMARY

In January 1982 the author visited the United States to attend and present a paper at the 12th Conference on Severe Local storms in San Antonio Texas. This report highlights certain aspects of that conference and details other discussions held both before and after the conference with the NOAA Environmental Research Laboratories, the FAA, the NASA Langley Research Centre and the National Severe Storms Laboratory.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories, P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

CONTENTS

LIST OF APPENDICES

1. Itinerary.
2. Program of 12th Conference on Severe Local Storms.
3. "Vertical Profiles of Wind Speed in Thunderstorm Gust Fronts" by Douglas John Sherman.
4. "Military applications of meteorological satellites: evolution and future" by Brigadier Albert Kaehn.
5. NASA Langley Research Centre - Organisation chart.
6. Review of gust loads on aircraft by John Houbolt.
7. VG/VGH general aviation program by Joe Jewel.
8. VGH Program - Wide body jet transports by Joe Jewel.
9. Digital VGH program by Derry Mace.
10. Storm hazards program by N. Crabill.

10A. Thunderstorm turbulence by R. E. Dunham.

11. Power spectrum of turbulence with a slope of -1 by Harold Murrow.
12. Active controls for flutter suppression by Harold Murrow.
13. Wind shear by R.E. Dunham.
14. Wind hazard models for piloted aircraft simulations by Roland L. Bowles.
15. Clear Air Turbulence by Mike L. Kaplan.
16. DVGH Program Phase 2 by John Finger.

LIST OF ACRONYMS AND INITIALS

AFOS	-	Automation of Field Operations and Services
AMS	-	American Meteorological Society
AWS	-	Air Weather Service (U.S. Air Force)
BAO	-	Boulder Atmospheric Observatory
CAT	-	Clear Air Turbulence
DAST	-	Drones for Aeronautical & Structural Testing
DMSP	-	Defence Meteorological Satellite Program
DVGH	-	Digital VGH
ERL	-	Environmental Research Laboratories
FAA	-	Federal Aviation Authority
FMCW	-	Frequency Modulated Continuous Wave
JAWS	-	Joint Airport Weather Studies Project
LaRC	-	Langley Research Centre
NCAR	-	National Centre for Atmospheric Research
NOAA	-	National Oceanic & Atmospheric Administration
NSSL	-	National Severe Storms Laboratory
PPI	-	Plan Position Indicator
PROFS	-	Prototype Regional Office Forecasting System
VG	-	Velocity/Gravity
VGH	-	Velocity/Gravity/Height

1. INTRODUCTION

The primary purpose of this visit was to attend and present a paper at the 12th Conference on Severe Local Storms in San Antonio, Texas. The paper, which was titled "Vertical Profiles of Wind Speed in Thunderstorm Gust Fronts" was presented at a poster session, and a handout was made available to interested people. Photographs of the poster display are shown in figures 1 and 2 and the handout is reproduced as Appendix 3.

A secondary purpose of the visit was to hold discussions on turbulence and wind shear problems related to aircraft. Discussions were held with the NOAA Environmental Research Laboratories and the National Centre for Atmospheric Research at Boulder, Colorado, with the Federal Aviation Administration in Washington D.C., with the NASA Langley Research Centre in Hampton, Virginia, and with the National Severe Storms Laboratory in Norman, Oklahoma.

2. PROGRAMME

The author departed Australia on 5th January, 1982 and returned on 26th January, 1982. During this period the following visits were made;

Thursday 7th January	-	NOAA - Environmental Research Laboratories,
Friday 8th January	-	and National Centre for Atmospheric Research, Boulder, Colorado
Monday 11th January to	-	12th AMS Conference on Severe Local Storms at
Friday 15th January	-	San Antonio, Texas.
Monday 18th January	-	Federal Aviation Administration, Washington, D.C.
Tuesday 19th January to	-	NASA Langley Research Centre.
Thursday 21st January	-	Hampton, Virginia.
Friday 22nd January	-	National Severe Storms Laboratory, Norman, Oklahoma.

Contacts and postal addresses are given in Appendix 1.

3. VISIT TO NOAA ENVIRONMENTAL RESEARCH LABORATORIES (ERL) AND NATIONAL CENTRE FOR ATMOSPHERIC RESEARCH (NCAR)

The visits were organised by Dr. Joe Golden and discussions were held with:

(a)	Chandran Kaimal	-	BAO Tower
(b)	Alan Bedard	-	Downdrafts in thunderstorms
(c)	John McCarthy	-	JAWS
(d)	Jack Hinkelman	-	Aircraft Studies of turbulence & PROFS
(e)	Don Beran	-	PROFS
(f)	Jack Hinkelman	-	Tour of PROFS system
(g)	Dr. Robert Lawrence	-	Optical remote sensing
(h)	David Hogg	-	Profiler
(i)	Bob Maddox	-	Thunderstorm Clusters
(j)	Fernando Caracena	-	I.R. sensing of temperature differences associated with turbulence and wind shear
(k)	Donald Lenschow	-	Aircraft instrumentation and measurements
(l)	Doug Lilly	-	Global energy dissipation above Boundary Layer in troposphere, and present WMO attitudes towards CAT.

Chandran Kaimal told me about the Boulder Atmospheric Observatory (BAO) tower. It is a 300 m high tower which has been specially built for atmospheric observations. It is not used for radio or television transmissions. It has been instrumented at eight levels, 10 m, 22 m, 50 m, 100 m, 150 m, 200 m, 250 m, and 300 m, and there is also a moving carriage which runs up and down the tower with variable height instruments. At each of the eight fixed levels there is a 3 axis acoustic anemometer (used to measure wind speed only, not temperature), a fast response temperature sensor using an exposed platinum wire, a quartz thermometer which gives accurate mean temperatures and a dewpoint hygrometer made by Cambridge Systems. The latter seems to be accurate to ± 1° over a 3-4 year period.

The data is sampled at 10 Hz and processed in a computer at the base of the tower. Low frequency filtered data is transmitted at 0.1 Hz and every 20 minutes the spectra of w', T' and w'T' are also transmitted. Each of these spectra is in fact the average of 10 unnormalised spectra computed from each two minutes of data. The spectra of the low frequency data are later computed using 100 minute data blocks.

Kaimal has found that if periods are chosen when the wind speed constitutes a stationary process, then the maximum on the spectra of longitudinal, transverse and vertical wind speed all occur at consistent frequencies. In other words the length scale L of the turbulence is well defined. However, mostly the data is non-stationary and in these cases the spectral maxima for the different wind components occur at different frequencies. Kaimal has devoted considerable effort to finding an algorithm to remove trends in the data, so that the length scale of the turbulence can be defined. He has concluded, however, that such a procedure is not possible for the longitudinal and transverse wind components, and that in the atmospheric boundary layer an integral length scale can only be defined for the vertical component of the wind vector.

Much of the work done with the BAO tower data relates to problems of air quality, dispersion, and the properties of elevated layers. There is a lidar about half a kilometre away from the tower which is used to measure pollutant concentrations in elevated layers. A particular problem at Boulder is oil fog at night.

Another problem is connection with air quality problems is that of flow over complex terrain, including such problems as the drainage wind, sea breezes and the effects on transport and dispersion. Over complex terrain the main problem is one of transport rather than dispersion. Such problems arise in connection with "smart" bombs and have been given considerable emphasis by the Department of Defence. In the presence of smoke, cloud, fog and dust such questions as "can I hit the target in five minutes?" usually resolve to questions of "which way is the wind blowing?".

Al Bedard discussed work he was doing on downbursts and micro-bursts. He was looking for data on the variation of downdraft speed with altitude, and I agreed to send him more data on the downburst on 5th November, 1977, reported at the Airmet conference in the paper by Meighen, Sherman and Thomson (1978). He mentioned the importance of the dynamic pressure head of the falling downdraft, and cited a case in which the pressure rose 5 mbar and fell again to the original value within a 10 minute period. He told me of an interesting case where a gust front propagated above an inversion,

and he also mentioned some measurements that had been made of downbursts at Atlanta, Georgia. These measurements followed a case in which a pilot experienced nearly the same wind shear problems as arose with the accident at JFK airport. The measurements are probably quite significant for Australia as they disclosed a very difficult situation for a pilot to negotiate in an area where the storm hazard is probably no more severe than it is at (say) Brisbane airport.

John McCarthy is a member of NCAR and is in charge of the JAWS project. JAWS is an acronym for a co-operative program between NCAR, NASA Langley, the University of Chicago, the National Science Foundation and the FAA, and circulars have been sent out inviting other people interested in the data that will be obtained to suggest desirable data to collect. The purpose of the program is to carefully describe some mesoscale low level wind shear situations, particularly involving convective wind shear and micro-bursts. (According to Fujita's definition, a micro-burst is a phenomenon occurring on a 2-5 km scale and a downburst is one on a larger scale). The dual-Doppler radar measurements which have been made so far have had a baseline of around 60 km. Because of the beam width of the radar this offers poor resolution of mesoscale flow structure. In the JAWS program a baseline of 25 km will be used. Trial will also be made at Denver airport of six different systems for wind shear detection and warning, and there will be a Doppler radar placed looking up the glide slope. This radar will be placed on a 3° slope and resolution along the beam will be about 150 m. Special aircraft flights will be made using the NASA B57 (instrumented for the lateral gust variation measurements) and three other aircraft (presumably from the NCAR flight wing). Possibly the English Airborne Lidar operated by the Royal Aircraft Signals Establishment in Malvern will also be involved. On occasions special attempts will be made, to obtain pilot reports from aircraft landing at Denver, but it does not seem feasible to obtain readouts from the DFDR because of budget limitations. The Doppler radar data will be used as input to a flight simulator and experiments will be made of different PPI displays of the Doppler radar data - e.g. displays of measured wind component V, and of increment ΔV over a distance Δx corresponding to about 1/2 the phugoid frequency.

John McCarthy mentioned that microbursts may occur unrelated to thunderstorms. He cited a type of situation that occurs fairly frequently in the Western part of the great plains where the air may be dry and a cloud may form with a cloud base around 10,000 ft. and cloud top around 17,000 ft. Such a cloud is very cold because of its extreme altitude, and may give rise to virga-water or ice precipitation which evaporates in the dry sub-cloud layer before it reaches the ground. Such evaporation cools the air which falls in a downdraft and

strikes the ground in a micro-burst which may give rise to wind speeds of 50 or 60 knots. Such micro-bursts are commonly made visible by the clouds of dust they stir up where they strike the ground. They are presumably similar to the Australian phenomena described by Radok (1948) and Desmond and Radok (1949).

Don Beran discussed PROFS which is a means of technology transfer to the operational meteorologist, particularly taking account of mesoscale and local scale processes. It represents the next generation of system beyond the AFOS system of the present American meteorologist. It emphasises a system approach, bringing together both satellite photographs and Doppler radar images as well as other data sources in ways designed to complement each other, one source settling ambiguities in the other. It requires high data rate processing and uses a colour video display. The present prototype system covering the Colorado area obtains data from twenty automatic weather stations over a length scale of about 12 km, whereas normally there would only be 2 weather stations in that area. PROFS will use the PROFILER system to measure the profiles of wind, temperature and humidity, and will have two standard (non-Doppler) weather radars connected, and access to the NCAR doppler radar. Beran stated that although the research community was now experimenting with mesoscale numerical models, they were not yet developed to a stage where they could be applied operationally.

Jack Hinkelman showed me the system which was based on three VAX computers (two model 11/780 and one model 11/750) with a fourth one standing by to deal with input from the NCAR Doppler radar. The automatic weather stations feed in 5 minute average values of measured parameters, and the standard radars feed in a PPI taken with a 1/2° elevation angle every 5 minutes (at 9,600 baud) plus a full volume scan every half hour. Satellite data will be fed in at 19,200 baud and when the doppler radar is connected it will feed in data at 56 kilo-baud.

Dr. Robert Lawrence discussed optical remote sensing and the scintillation of light (e.g. twinkling of stars). The cause of the scintillation is phenomena which he calls "optical turbulence" which is primarily due to changes in air density because of changes in temperature which occur on a scale size of a few centimetres. In fact ΔT can be as large as 10° in a few millimetres, Kaimal and Gossard are working to find temperature gradients in a stable atmosphere. In a neutral atmosphere there are intermittent sharp changes in temperature, which are definitely not Gaussian, their probability distribution is more like the log-Normal one.

David Hogg has been working on the development of the profiler which has been developed in two versions, one using VHF and one using UHF. The profiler looks as though it could replace balloon soundings with the advantages that radio soundings are made at about 20 or 30 minute intervals, and the soundings can extend up into the ionosphere. Because of the narrow frequency allocation the VHF version of the profiler has a much poorer resolution of height variations than the UHF version, but is much cheaper. A solid state amplifier for the UHF transmitter (which needs considerable power) costs more than $200,000. Velocity vectors are measured by three doppler beams, one vertical and two inclined at 15° angles in the North and East directions. A paper on the profiler was presented at the AIAA meeting in Orlando, Fla. January 1982.

Bob Maddox discussed the way in which satellite photography had shown several instances of thunderstorm clusters called mesoscale convective complexes, which were of the order of 1,000 km across. These clusters interact to affect the larger scale flow. Bob Maddox had a paper on the subject in the Severe Storms Conference.

Lois Stearns and Fernando Caracena discussed the use of infra-red devices looking ahead of an aircraft in a horizontal direction to detect wind shear and clear air turbulence.

Donald Lenschow is in charge of the NCAR aircraft flight. They presently have four aircraft, an Electra, a Sabreliner and two Beechcraft Queenairs, one of which is soon to be replaced by a Kingair. All are equipped with INS systems and gust probes. The data from the Sabreliner are only sampled at 1 Hz but the others can sample at sufficient frequency to describe gusts. The gust probes use fixed vanes and differential pressure measurements. The head of the probe is hemispherical with holes at appropriate points, and the pressures were measured with Rosemount sensors. Donald Lenschow designed a lot of the instrumentation but in more recent years he has been more involved with the analysis of aircraft measurements from the atmospheric standpoint, such as the determination of fluxes of moisture, ozone etc., especially in boundary layer flying.

Doug Lilly mentioned some work he had done on dissipation in the stratosphere in conjunction with the HICAT workers, and other work on global dissipation in the troposphere above the boundary layer. He had also been nominated recently as WMO rapporteur on CAT and had produced a report stating that since the airline operations no longer showed any concern about CAT it appeared that the combination of present day avoidance techniques and methods of handling CAT when it occurred was satisfactory, and there was no great demand for further work on the subject. Some incidents discussed later at NASA threw some doubts on this opinion.

4. ATTENDANCE AT AMS CONFERENCE ON SEVERE LOCAL STORMS SAN ANTONIO, TEXAS

4.1 AMS Annual Meeting

This conference was held in conjunction with the American Meteorological Society (AMS) 62nd annual meeting and the Third joint conference on applications of air pollution meteorology. Preprints of the 12th Conference on Severe Local Storms (AMS 1982) were available to registrants for this conference. A list of conference sessions is shown in Appendix 2. The author's paper was a late entrant, so did not appear in the pre-prints. A handout was made available at the conference and this is reproduced as Appendix 3. There were no pre-prints for the AMS annual meeting although this included a very interesting session on Monday 11th January titled "Meteorological satellites - Their conception, growth, accomplishments and future". Two noteworthy papers presented at this session were:

"Initial proposals reviewed relative to satellite program developments" by William W. Kellogg of NCAR, Boulder, Co., and

"Military Applications: Evolution and Future" by Albert Kaehn Jr., Air Weather Service, Scott AFB, Ill. (see Appendix 4).

Dr. Kellogg's paper was a historical review. In 1945, after the war, Dr. Kellogg was a member of the upper atmosphere V2 panel. Some German V2 rockets were being experimented with in the USA, and in some of them, to replace the concrete being used to ballast the front end, some meteorological instruments and cameras were installed. In 1947 Dr. Kellogg joined the RAND corporation who even at that early date were working on the design of an Earth Satellite. In 1949 the January issue of the Bulletin of the American Meteorological Society carried an article and cover picture on cloud observations from rockets, and in 1951 Professor Bjerkness produced, under contract, a secret report on the meteorological use of rocket photographs, unaware that the intended application of his report was in fact to satellite photography.

Brigadier Kaehn indicated that, although in peace-time the Air Force's Air Weather Service (AWS) made use of data from many sources, in war-time it could not count on these sources, but only on the Department of Defence Meteorological Satellites, DMSP. These are polar orbiting satellites and there are at least two of these satellites at all times.

The Air Weather Service is given high priority by the Department of Defence because of the extremely weather sensitive nature of new weapons using TV, IR or laser guided systems. The DMSP satellites operate with both recorded mode transmission and direct mode transmission to provide data for both tropospheric missions and ionosphere missions, and since 1976 they have been fitted with an improved cloud sensor. Some of their unique features are that they operate under DoD command and control, have encryption of data, orbit optimisation for DoD MetSat purposes, flexibility and minimised readout times. They can distinguish between snow and cloud, locate the auroral oval, and parameters such as sea surface temperature (of special interest to the Navy) are also available. Recorded data is processed at the AFGWC to give a world forecast and direct data can be received by a transportable tactical terminal van in the battlefield situation to assist in combat operations. The system is highly responsive as the program can be changed in 6 hours and the digital data base has a 3 n.mile resolution.

Data processing is highly automated, with a global data base, a cloud analysis model using visual and IR images and temperature soundings, to produce an automated cloud forecast model. Analyses are kept updated so they always include the latest satellite data. A data reliability figure of 95% was quoted.

Tactical uses of the system were briefly mentioned, including such subjects as combat target acquisition and crisis data denial. For example, many missions would not have been launched without DMSP photographs. The Son Tay raid in Vietnam to release a number of prisoners was made to coincide with the weather break between two storms. DMSP photographs meant that weather reconnaissance flights which might have alerted the enemy were not necessary. Dr. Kaehn also mentioned that during the Yom Kippur war certain nations stopped the exchange of weather information, despite international agreements to the contrary, in order to deny information to their enemies.

The Joint Typhoon Warning Centre was mentioned with the significance of storm warnings in the protection of DoD resources. The particular importance of the Western Pacific area (50% of satellite storm positions) in this respect was remarked.

In summary the importance of the DMSP was noted for:

- Space environment missions
- Top side ionosondes
- Microwave imagery

- Automated image processing
- Improved cloud analysis and forecasting.

Improvements to the transportable tactical terminal van will enable it to handle microwave imagery and atmospheric soundings.

The DMSP data is shared with the US Civilian Meteorological Service, but not shared on a real time basis with other countries. On an archival basis the data are stored at and publicly available from the University of Wisconsin.

4.2 Gust Fronts

Some of the papers of special interest in relation to gust fronts were:

4.5 "A Semi-Lagrangian numerical gust front model" by Gary L. Achtemeier, Illinois State Water Survey.

6.1 "Model and observations of a waterspout bearing cloud system" by Joanne Simpson, NASA Goddard Space Flight Centre.

6.3 "A new look at the vorticity equation with application to tornadogenesis" by Robert Davies-Jones, NSSL.

10.1 "The life cycle of thunderstorm gust fronts as viewed by Doppler radar and rawinsonde data" by Roger Wakimoto, Univ. of Chicago.

12.5 "Thunderstorm trigger mechanisms over the southeast United States" by James Purdom, Colorado State Univ., and Kevin Marcus, Earth Satellite Corp.

13.3 "The roles of thunderstorm outflows in the production and maintenance of convection" by K. K. Droegemeier and Robert Wilhelmson, Univ. of Illinois.

In paper 6.1, Joanne Simpson pointed out that water spouts occur right on the edge of the gust front, and in paper 6.3 Robert Davies-Jones points out similarly that tornadoes occur on the edge of the gust front. Joanne Simpson suggested that when the horizontal axis vorticity in the boundary layer flow meets the gust front moving towards it, the vorticity is lifted, giving it a vertical component which can then undergo processes of amplification.

In paper 12.5, Purdom and Marcus point to the possibility of two intersecting gust fronts giving rise to a zone of lifting air which may then trigger a new thunderstorm.

4.3 Other Points of Interest

Fujita (paper 5.7) mentioned an idea which he attributed to David Atlas. The temperature of cloud tops as measured by satellite IR sensors, may be different from the general air temperature in the cloud top because the IR sensors measure temperature in a very thin layer at the surface of the cloud and this temperature may be greatly affected by surface mixing in a relatively thin layer around 50 m to 200 m thick.

Colgate (paper 6.2) stated that warm dry air found in association with tornadoes need not be brought down from very great altitudes as sometimes suggested. He proposed the theory that moist air is sucked into a tornado wet adiabatically, condensation occurs and the moisture is centrifuged out, then the air is re-compressed dry adiabatically, becoming very warm and therefore of much greater buoyancy.

One author (I think it was Colgate when presenting paper 9.8) mentioned that he made use of Loran C in an unusual application to measure aircraft position with an accuracy of 70 m.

5. VISIT TO FEDERAL AVIATION AUTHORITY, WASHINGTON D.C.

The visit was organised through Charles Jones of the FAA, who arranged a discussion with Myron Clark and Herbert Schlickenmeier. At this discussion, Huib van der Weyden, an engineer from the Department of Civil Aviation in the Netherlands was also present.

The first topic of conversation was wake vortices. Huib van der Weyden told of some work he had been concerned with in the Netherlands using a line of anemometers with a height of 2½ m across an airfield. He also mentioned work at Delft University where an FMCW radar was used and an F28 flown across the radar site. Myron Clark mentioned similar work done by Chadwick at the Wave Propagation Laboratory in Boulder, where signals from the wake vortex had been seen as far out as 1 km. Dr. Weber from the DFVLR was also working on the problem at Frankfurt where the parallel runways were particularly close together, perhaps only 700' to 1500' apart.

Herbert Schlickenmeier, who was concerned with turbulence models for simulation purposes, mentioned the Tomlinson model, which had been developed in England for the Civil Aviation Authority, and said that he believed some work was being done by Calspan for NASA on the implementation of this model.

The FAA said that two commercial airline groups were using the Aircraft Integrated Data System (AIDS) and that in particular TWA were reading the recorders after every flight, mainly as a management tool. They believed that this data (at least the TWA data) was stored in Kansas City and, possibly, made available to NASA. (Later discussion at NASA found that this was not so).

They also mentioned that some work had been done (as recently as last summer) on the detection and avoidance of CAT by Jim Bilbro at NASA-Marshall.

Craig Goff is working at Atlantic City on the wind shear program. He has much data which has been compiled and put into a central data base. There is no catalogue yet for this data base but as of a year ago Craig was working on such a catalogue. He was also analysing some data to compare the persistence of the vertical wind component at low altitude (around 100 m) with the persistence of the horizontal component.

It was thought that the RAE Bedford had, 2 summers ago, been working on a laser looking ahead from a HS-125 for wind shear and turbulence. Lockhead Burbank had also been working on laser instrumentation and had developed a laser version of CADC (Air Data Computer). Using a Tristar with a 3 component laser focussing on a point, looking perpendicular to the flight path out to the side of the aircraft they were able (or trying?) to measure directly the air speed (molecular flow over the top of the wing) and altitude.

6. VISIT TO NASA - LANGLEY RESEARCH CENTRE

The main contact for this visit was Norman Crabill, and discussions were held with:

(a)	Norman Crabill and Derry Mace	-	Digital Vgh program
(b)	Dr. John Houbolt	-	Overview of NACA-NASA atmospheric turbulence measurements
(c)	Joe Jewel.	-	Vgh General aviation and transport aircraft results
(d)	Norm Crabill	-	Current NASA digital Vgh program
(e)	John Houbolt and W.D. Mace Jnr.	-	Continuous turbulence analysis and results

(f)	Norm. Crabill	-	Thunderstorm turbulence and lightning effects
(g)	Harold Murrow	-	Spanwise gust gradient flight measurement program
(h)	Harold Murrow	-	Flight testing for active controls
(i)	Norm. Crabill	-	R.E. Dunham's wind shear measurements
(j)	Roland Bowles	-	Wind shear simulation
(k)	Mike Kaplan	-	Mesoscale atmospheric simulation system and accident on 3rd April 1981 near Hannibal Missouri
(l)	Joe Jewel	-	Status of Vgh measurements made in Australia
(m)	Roland Bowles and John Houbolt	-	Simulation models, Power spectral and statistical discrete gust models
(n)	John Finger	-	Aircraft instrumentation associated with the crash recorder, and the next phase of the digital Vgh program.

The administrative structure of the NASA Langley Research Centre (LaRC) is shown diagramatically in Appendix 5.

Norm Crabill and Derry Mace showed me some of the work they go through with the digital Vgh program. Despite running a computer error correction program on the data there is still a large amount of manual correction, identification and bias removal work needed. The result is that the rate of data acquisition is not significantly faster than for the old analogue Vgh program.

The aircraft weight at any time is calculated by a linear interpolation between take-off weight and landing weight. This simple calculation is, they find, within 2% of an assessment made using a much more complex model. The lift curve slope is, when no flaps are extended, a function of Mach number and altitude. When flaps are extended, the lift curve slope is solely a function of the flap setting, since when flaps are extended the Mach number is low and for low Mach numbers the lift curve slope is not a function of altitude.

When the autopilot is connected, the gust response characteristic of the aircraft is considerably altered. For some purposes they are able to simply multiply computed A and No values by fixed factors. In my opinion, however, the overall philosophy of the approach to the problem requires further consideration.

John Houbolt gave a talk, using a set of overhead transparencies (see Appendix 6) on aircraft response to gusts. He pointed out that NACA had been a very early worker in gust response, dating from NACA Report No. 1 by Hunsaker. He mentioned the early work when the gust alleviation factor, K, was taken, somewhat arbitrarily as a function of wing loading, and the later developments when the alleviation factor, Kg, was a function of the mass parameter, μ. He mentioned the power spectral models and the ALLCAT program. He talked about peak counting, the importance of including the pitch degree of freedom in realistic aircraft models, and work he had done re-analysing Peckham's data to find new values for P_1 and P_2, b_1 and b_2. Because the response of a two degree of freedom aircraft model has a peak at a much higher frequency than a one degree of freedom model, he has developed a transformation of the turbulence spectrum which, by simple scaling, brings the spectra for all values of 2L/c onto a single curve at the high frequency end. The predominant response of the two degree of freedom aircraft model is in this universal range, so that it is possible to develop a gust response theory which is much more independent of the length scale of the turbulence.

Joe Jewel gave two talks on Vgh programs, one on general aviation aircraft and one on jet transports. These talks were supported by overhead transparencies which are reproduced in Appendices 7 and 8.

Norm Crabill gave a talk about the digital Vgh program in which he indicated that to deal with the effect of the autopilot he multiplied the values of A by 0.8 and the values of N_o by 1.2 during the times the autopilot was on. He also indicated that for about 15% of the time the records showed the presence of an autopilot induced oscillation when the autopilot was on in the altitude hold mode.

Derry Mace indicated that they were using values of N_o calculated from Houbolts two degree of freedom model. He also showed graphs of some of the early results (see Appendix 9).

Norm Crabill told of the NASA program on storm hazards. The set of transparancies for this talk constitute Appendices 10 and 10A. NASA have equipped an F106 with a gust probe measuring total head with a sensitive transducer and flow vanes to measure gusts.

Vertical acceleration is recorded at 10 Hz. There is a Doppler radar fitted in the nose cone and instruments to measure electric and magnetic transients are installed in various parts of the aircraft. The aircraft has a composite fin cap which has been covered with an aluminium coating.

If an aircraft is struck by lightning the electric charge will usually enter the aircraft at some electric field concentrator such as a rivet. As the aircraft flies forward charge tends to continue flowing into the same point through a plasma channel which forms in the air adjacent to the aircraft until another electric field concentrator comes near the lightning stroke position, when the lightning entry point changes to the new position. The result is that as the aircraft flies through the lightning stroke a line of points of charge entry (swept stroke) occur parallel to the flight path. Contrary to previous expectations it has been found that these lightning strike positions can occur at mid-chord positions on the wing and so there is some danger to the fuel tanks. The initial electric flow is used to charge up the aircraft, but at a late stage in the process the aircraft will discharge, usually from a trailing electric field concentrator such as a fin tip, wing tip, or trailing edge. At this stage considerable metal erosion may occur from the discharge point.

Harold Murrow discussed the program to instrument a B57B (Canberra) aircraft to measure the spanwise variation of gusts. The Canberra was chosen because it has a very stiff wing structure, but even so it is a fairly demanding requirement to obtain useful data by filtering data with a low pass filter to cut out variations at or above the fundamental wing bending frequency of 7.2 Hz. The wing span is 60 ft approx., and the air speed proposed is about 300 ft./sec., so one cycle per span corresponds to a frequency of 300/60 = 5 Hz.

The Canberra had previously been in use collecting data on aircraft encounters with different types of turbulence, using a single gust probe with balsa flow vanes to measure transverse gust velocity components and a sensitive pressure sensor to measure the longitudinal component. Samples of data from convective, wind shear, rotor and mountain wave turbulence are shown in the paper by Rhyne, Murrow and Sidwell (1976). He also showed an interesting case where a power spectrum with a -1 slope was encountered (see Appendix 11). At present no explanation is available.

Hal Murrow also gave a talk on the DAST (Drones for Aeronautical and Structural Testing) Program. This is a program for carrying out risky testing using drones with a size around 14 ft wing span (wing area of 30 sq.ft.). The emphasis is on the transonic region, using transport type wings with aspect ratio around 6-10.

In order to study [illegible] aeroelastic effects they have built an aeroelastic wing which exhibits explosive flutter within the flight envelope, using fibre-glass skins. They are testing the effects of both active controls and tailored composites on flutter suppression. The program is a joint one between the Langley and the Dryden research centres. The drone is flown by a test pilot using controls on the tail plane, while the experimenter independently excites the wing and switches the active control system on. Because the drone can only fly supersonically for about 2[illegible] minutes it is launched from under a B52 wing. At the end of a flight a parachute deploys and a helicopter moves in to catch the drone and place it gently on a special pad. The talk was partly based on the two papers by Murrow and Eckstrom (1979) and be Perry et al (1980). Two examples of the effect of flutter suppression are shown in Appendix 12.

Norm Crabill discussed the program of low level wind shear measurements made by R.E. Dunham using the digital flight data recorders on INS fitted aircraft. (See Appendix 13).

Roland Bowles (see transparency copies in Appendix 14) discussed the problems of modelling atmospheric phenomena such as wind shear and turbulence for aircraft simulators. He pointed out that even within one organisation there were likely to be a number of models of such phenomena used by different people or for different purposes. He pointed to the desirability of standardising simulation models and of developing appropriate design criteria for the man/machine interface. He gave his opinion that the simulation community does a poor job in simulating aviation meteorology and mentioned a draft standard proposed by the FAA (FAA 121 Part H) which is a 3-phase program aimed ultimately at the 100% training of pilots in simulators. This proposal set some difficult requirements for the simulation of weather, and on the overall aim of the program he thought we were not yet there in technology, although the technology was perhaps half-way there.

In response to a question concerning the relative importance of thunderstorms, rain and other situations, he mentioned an accident at Denver, where a Continental 727 encountered a gust front about three miles from the airport after take-off. It is thought that this may have been a downburst in dry air, and he thought that given the noise abatement procedures in use at the time there was nothing that could have been done to save the plane.

For problems involving wind shear he defined a parameter

$$\sigma = \frac{\text{TAS} \times \text{wind gradient}}{g}.$$

which is in fact proportioned to the phugoid frequency. If this parameter is greater than 0 we have a situation of decreasing head wind, and if it is less than 0 we have a situation of increasing head wind. For a typical jet transport the value is between -4 and +4. (The accident at JFK airport occurred with $\sigma \simeq +4$). Roland produced a table showing that as σ increased over the positive range the time to double the amplitude of the phugoid oscillation dropped from a couple of minutes or so down to only a few seconds.

Mention was made of a draft advisory circular, AC-120, for the approval of airborne wind shear detection systems.

In tests that had been made so far with different simulation models of wind shear, it was found that the models which the pilots had most difficulty in flying were also the models which they rated as most realistic on simulating the feel of turbulence. However, all the models were criticised on this aspect as being "randomly monotonous".

Mike Kaplan discussed his mesoscale atmospheric simulation system (MASS). He used a series of transparencies which are reproduced in appendix 15. MASS is a 14 level numerical model with a very fine (157 x 117) horizontal grid. Using the NASA Cyber 203 it can simulate a 24 hour period in 30 minutes of computer time.

He discussed the weather situation at the time an accident happened to a DC-10 on 3rd April 1981 near Hannibal, Missouri. Vertical gust velocities up to 125 ft/sec. were encountered by flight UAL-12 at 0125 GMT. The conditions occurred near 37,000 ' in a very narrow jet core. The conditions had not been predicted by the weather service because the nearest balloon sounding had been lost (blown away) a little below this level. Using the MASS model it was possible to predict the strong jet stream core and predict the occurrence of a cats eye flow pattern.

Joe Jewel prepared for me a list of all the NACA-NASA reports on Vg and Vgh programs. This list is reproduced below.

ATMOSPHERIC TURBULENCE

NACA - NASA VG - VGH REPORTS

Report	Commercial Transport	Cargo Carriers	Aircraft type
NASA TN D-8481	√		
TN D-6790		√	
TN D-6124	Landing impact and taxi loads		
TN D-4529	√		
TN D-4330	√		
TN D-1811	√		
TN D- 744	√		
TN D- 36	√		
TN D- 29	√		
MEMO 4-17-59L	Atmo. Turb. between 20 and 55 thousand feet		
TN D-2740	√		
NACA RM L57L12	Flt. Invest. of jet stream		
NACA TN 4129	√		
NACA RM L57G02	Atmo. Turb. between 20 and 50 k ft. over Western U.S.		
NACA RM 57A11	Atmo. Turb. over England and Western Europe Feeder line over Rocky Mountains		
NACA TN 3750	√		
NACA RM L55H04a	Atmos. Turb. Jet Stream		
NACA TN 3483	√		
NACA TN 3475	√		
NACA TN 3371	√		
NACA TN 3365	√		
NACA RM 54F07	Atmos. Turb. associated with jet stream		

.../cont.

NACA - NASA VG - VGH REPORTS (CONT.D)

Report	Commercial Transport	Cargo Carriers	Aircraft Type
NACA TN 3086	✓		
NACA RM L53G15a	Atmo. Turb. variation with altitude		
NACA TN 2663	✓		
NASA TN D-5601			
TN D- 548	Atmo. Turb. between 20 and 75 k		
NACA TN 2625	VG Data from a number of aircraft flown from 1933-1945 ✓		
TN 1783	VG data ✓		
TN 1754	VG data ✓		
TN 1693	VG data ✓		
TN 1142	VG data ✓		
TN 1141	VG data ✓		
TN 2176	✓		
RM L 57L12	Atmo. Turb. over Western U.S.		

Joe Jewel discovered that quite a large amount of Vgh data had been collected in the Australian program - 1546 hours from the Ansett plane VH-CZA and 1768 hours from the TAA plane VH-TJK. This data had been read off and computerised and an estimated 3 ft. stack of print-out had been a record of this. On 31st October 1977 this data had been sent with other DC-9 data amounting to 27 boxes in total, to -

Mr. John E. King,
Douglas Aircraft Company,
Mail Code 35-25,
3855 Lakewood Blvd.,
Long Beach, Ca 90846.

The present contact at Douglas Aircraft Company is Paul Abelkis, phone (213) 593-5260. Unfortunately a few months ago the area in which this work was dealt with at Douglas was moved to a new building and it is not presently known what happened to the data. (Later correspondence states that Paul Abelkis advised that the 27 boxes of DC-9 data could not be located at Douglas and are presumed destroyed. See ARL file G5/179/201 f 42).

Roland Bowles indicated that CALSPAN were testing the Tomlinson model for the simulation of turbulence and Houbolt indicated that the simulation of turbulence would he believed, feel much more realistic to the pilot if the effects of pitching due to gust, the effects of roll due to lateral variation of gust and the effects of yaw due to lateral gust were all included in the simulator motions, and the pitch and heave motions reduced to more realistic values. Houbolt is presently working on a report on the 2 degree of freedom response to turbulence. He told me that the formula

$$Kg = \frac{0.88\mu}{5.3 + \mu}$$

had actually been derived by him as a curve fit to the graph in the report by Pratt and Walker. He also indicated that the first report to take account of wing bending had been NACA - R - 1010.

John Finger presented a talk on the phase 2 program proposed for the digital flight data recorder. (See the transparencies in Appendix 16). The normal aircraft "crash recorder" system includes a large number of sensors which feed data to the flight data acquisition unit (FDAU) which acts as a multiplexer and feeds digital data to the digital flight data recorder (DFDR). This records on multitrack magnetic tape at 786 bits per econd on tape which moves at half an inch per second. Two manufacturers of FDAU units are Hamilton, who produce a dearer slightly better model having amongst other things two output ports in parallel, and Teledyne who produce a slightly cheaper version. The DFDR units are manufactured by Sunstrand and Lockheed. However only one of these DFDR units has the facility for fast replay and transcription in the aircraft, the other has to be removed entire and replayed at the Teledyne readout station.

John Finger, working for Research Triangle Institute under contract to NASA - Langley has tested the system extensively both in a test bed and on board an aircraft. The entire system appears extremely reliable and robust to a wide range of extreme conditions (e.g. over or under voltage, transients) except for the magnetic tape recording and replay system. It has been decided to build a new digital VGH system which will not record time history data but directly compute tables of exceedances of total acceleration, manoeuvre acceleration (i.e. low pass filtered acceleration) gust acceleration, U_{de} etc, and record these in solid state memory. It is proposed to operate the new system as a recorder in parallel with the DFDR working with the Arinc 573 digital data stream from the FDAU. The most likely recording medium at this stage is magnetic bubble using the INTEL "Plug-a-bubble" system which has been certified by FAA, can resist 50 g and has a heavy vibration specification. The proposed recorder will be a package around 13" x 7.625" x 4.875" weighing 4.5 lb and costing around $10,000 per recorder in 10 off quantities. As bubble technology improves it is anticipated that the plug-a-bubble units which at present cost $2,500 and store 1 megabit of data, will become cheaper and in the same package may store up to 8 or 16 megabits of data. This may given the facility, by reprogramming the software, to record limited time history data of extreme events.

7. VISIT TO NATIONAL SEVERE STORMS LABORATORY AT NORMAN, OKLAHOMA

The main contact was Mr. Jean Lee and discussions were held with:

(a) Ed. Kessler - Gust fronts

(b) Dick Doviak - Doppler radar measurements of turbulent velocity fields in clear air

(c) David Zittel - Tower data and error correction methods

(d) John Carter - Tower instrumentation

(e) Duzan Zrnic - Doppler radar

(f) Jean Lee - Aircraft gust encounters in thunderstorms.

Ed Kessler, in discussing the aeronautical hazards posed by gust fronts, expressed the view that it was better to have a warning device (such as a ring of anemometers around an aerodrome) which responded directly to the aeronautically significant parameter, rather than to a secondary parameter such as a pressure jump. In connection with pressure jumps he mentioned the large number of pressure jumps

in the atmosphere arising from various causes, and he quoted the 1963 paper by Chester Newton (Meteorological Monographs Vol. 5, No. 27 pp 33-55). He recommended reading the NTSB report on the Eastern Airlines accident at JFK airport.

He also mentioned that NSSL had a contract with MIT to use a flight simulator with a simulated convective wind field. It was found that when the pilot could not see the ground, accidents were likely under difficult wind conditions, but if the pilot could see the ground then it was very difficult to cause an accident.

Dick Doviak showed me some wind fields measured in clear air at an altitude of 1 km with a dual Doppler radar. The beam width was such that velocities were averaged from about 500 m altitude to 1.5 km altitude, and the area of coverage was about 25 km square. It was very noticeable that over a three minute period the mean wind field was convected with themmean wind with relatively little modification.

David Zittel discussed the error correction procedures that were used in connection with the WKY TV tower data (see the report by Goff & Zittel) and John Carter discussed the instrumentation of the tower. Aero vanes were fitted at 7 levels but usually the vertical velocity component was only measured at one, two or three levels. They used the Gill polystyrene foam blades, although they also had tried the polypropylene blades. One of their problems was ice forming on the tower and later dropping off in pieces which damaged many of the instruments. They used thermistors to measure dry and wet bulb temperatures, with the wet bulb kept wet by water from a reservoir carried up by a wick. Dust contamination was such that the wicks needed changing on a weekly basis, so the replenishment of the water reservoirs was not felt to be a problem. Pressure at the bottom and top of the tower was measured with an aneroid type bellows, approximately 2" in diameter, the moving side of which was connected to a piece of ferromagnetic material which moved inside a coil, presumably a variable reluctance transducer. Solar radiation and rainfall were measured at the surface. High speed data could be measured at 2 second intervals and normal data acquisition speed was from 10 second to one minute intervals. The instrumentation system had a large battery back up which could operate for approximately 12 hours, but even so whenever a power failure occurred there would be a data end of file initiated during the change-over from mains power to battery power. They found it necessary to have a pre-season calibration of the instruments in April and a post-season calibration in June. This was particularly necessary for the thermistors and the rotational sensors. John Carter mentioned that they would like to use the Setra quartz pressure transducer which had a very good specification but it was very expensive.

Duzan Zrnic showed me the Doppler radar instrumentation which had largely been built up at NSSL.

Jean Lee has done a great deal of work on aircraft penetrations of thunderstorms. He has a data bank, which could be made available, of about 400 hours corresponding to 20,000 miles of flying with about 1200 thunderstorm penetrations. Ideally, each penetration of a storm of diameter "D", started a distance D away from the storm cloud and ended a distance D away from the cloud on the other side, making a total flight path length of 3D. Lee concluded that:

1. turbulence of any significance was only found inside the visible cloud;

2. only about 30% of the cloud was turbulent, so that there was a reasonably high probability that on any single penetration of a storm no turbulence would be encountered.

3. Turbulence could be encountered anywhere in the visual cloud, and the location of the turbulence was quite independent of the location of the strong radar echoes.

4. The severity of the maximum turbulence likely to be encountered in the cloud was, however, dependent on the intensity of the maximum radar echo found in the cloud. On this basis NSSL had recommended to the FAA that aero planes should stay out of any storm in which an echo of 40 dBZ occurred.

Over the years pilots had been getting bolder and flying closer to thunderstorms so that more turbulence is being encountered. The traditional practice in the United States is, at low altitudes, to keep 10 miles away from a radar echo because the visual cloud may extend a considerable distance beyond the radar echo, and at high altitudes to keep 20 miles away from a radar echo because thunderstorm clouds may grow quite explosively over time scales comparable with the time for the aircraft to fly 10 miles.

Lee mentioned that over the years the radar intensity of storms seems to have become greater, but this is because of new corrections that have been made to the calibrations of radar units in more recent times, such as adding 5 dB to correct for the loss in the wave guide.

He also said that John Chapman of the Airworthiness Section, British Civil Aviation Authority, Red Hill, England has some Vgh type data that has been measured in thunderstorms. He also mentioned

that at the AIAA meeting which had been held in Orlando Fla at the same time as the Severe Storms Conference, it had been mentioned that some FAA specifications were outdated. There was an accident to a Southern Airlines plane due to the ingestion of too much liquid water. The FAA specification set the design condition as 9 gm water/Kg air whereas it is now known that water contents as high as 12 g/Kg can be encountered.

8. CONCLUSIONS

1. The values of the parameters P_1, P_2, b_1, b_2 and L for the American atmospheric gust model are not very well defined. The values in current use are tentative values derived in a series of studies aimed primarily at establishing the principle and the feasibility of the power spectral method. Therefore if the Australian gust model is to be satisfactorily established it will require more than an indicative comparison between the available Australian data and the present American model. A collation and re-assessment of all the available American Vgh data and a comparison with the available Australian data is a possible approach to the problem.

2. The situation is further complicated in that different values of the parameters are applicable depending on the aircraft model. In particular, if a 1 degree of freedom aircraft model is used a large part of the calculated response occurs at long wave lengths. For this reason great effort has been devoted in some experimental programs to accurately measuring the value of L, the integral length scale, which is of the order of a kilometre in the free atmosphere. However John Houbolt holds, apparently with very good reason, that it is necessary to use at least a 2 degree of freedom model of aircraft response. With a 2 degree of freedom model, the "weather cock" effect washes out most of the low frequency aircraft response whilst increasing the high frequency response. The precise value of L is much less important but different values of P_1, P_2, b_1 and b_2 are needed. So far no study has been made to establish or compare the parameter values needed for different aircraft models, and in most of the aeronautical community there appears to be little awareness of the fact that different parameter sets are needed.

3. There does not appear to be any significant amount of unpublished Vgh data available at NASA Langley, but the table of published references embodied in the text is a good pointer to the available civil data.

4. The present digital Vgh program is quite manually intensive. It would have to be established whether a more sophisticated error correction program could be made to function before there would be any

possibility of obtaining large quantities of data in a highly automated process. The phase 2 digital Vgh program will overcome this, but since no time history data are proposed it is not possible to check any extreme events occurring in tables of data. If Australia were to purchase some of the proposed Phase 2 recorders and fit them with the projected larger bubble memories the recorder software could be modified to enable some recording of extreme events.

9. REFERENCES

The reports received during this visit are listed by source as follows:

9.1 Reports received at ERL and NCAR

Due to a prolonged mail delay these are not yet available.

9.2 Reports received from FAA

Barr, N.M., Gangaas, D. and Schaeffer, D.R. 1974
Wind models for flight simulator certification of landing and approach guidance and control systems.
Report No. FAA-RD-74-206, AD-A003,801 (Reference only).

Frost, W., Camp, D.W. and Wang, S.T. 1978
Wind shear modelling for aircraft hazard definition.
Report No. FAA-RD-78-3.

Foy, W.H. 1979
Airborne aids for coping with low level wind shear.
Report No. FAA-RD-79-117.

Foy, W.H. and Gartner, W.B. 1979
Piloted flight simulation study of the low-level wind shear, Phase 4.
Report No. FAA-RD-79-84.

Ellis, D.W. and Keenan, M.G. 1979
Development of wind shear models and determination of wind shear hazards.
Report No. FAA-RD-79-119.

9.3 Reports received from NASA Langley

Crabill, N.L. Jan. 1980
Transport aircraft normal accelerations, gust experience, flap and spoiler usage during scheduled airline operations in 1973.
Draft report.

Morris, G.J. and Crabill, N.L. 13-16 Oct. 1980
Air transport flight parameter measurements program - concepts and benefits.
Paper to be presented at Society of Automotive Engineers 1980 Aerospace Congress, Los Angeles, California.

Crabill, N.L. and Morris, G.J. 5-7 Nov. 1980
The NASA digital Vgh program - Early results.
Proceedings of a conference held at NASA Langley Research Centre, Hampton, Va.

Keskar, D.A. 4 June 1979
Program description document for automatic edit program for digital Vgh data analysis.
Document PDD-79-01. Produced by SDC Integrated Services Inc., 3217 North Armistead Avenue, Hampton Va.

Mace, W.D. Approx 1978
Digital Vgh data analysis, Lockheed L-1011-Phase 1.
Memo from NASA Langley to Systems Development Corporation.

ANON 17 Dec. 1979
Digital Vgh Phase 2 Functional requirements
Memo from Aerospace Technologist, Safety and Operating Problems Branch, Flight Mechanics Division to Head, Safety and Operating Problems Branch.

KENTRON 8 Jan. 1980
Digital Vgh data handling and processing procedures.
Memo from Associate Engineer Kentron International to Digital Vgh Files.

Houbolt, J.C. Nov. 1973
Updated gust design values for use with AFFDL-70-106. AFFDL-TR-73-148

Houbolt, J.C. 17-18 May 1973
On turbulence environment and design criteria. Paper prepared for AGARD Flight Mechanics Panel Symposium Woburn Abbey near Bedford U.K.

Houbolt, J.C. 17-19 May 1972
Atmospheric Turbulence.
AIAA Paper No. 72-219. Presented at AIAA 10th Aerospace Sciences Meeting, San Diego, Calif.

Jewel, J.W. and Morris, G.J. Dec. 1975
A review of the NASA V-g/Vgh general aviation program NASA TN D-8058.

Zalovcik, J.A., Jewel, J.W. and Morris, G.J. July 1977
Comparison of Vgh data from wide-body and narrow-body long-haul turbine-powered transports.
NASA TN D-8481

Jewel, J.W. 1971
Progress report on the NASA V-g/Vgh general aviation program.
NASA Aircraft Safety and Operating Problems Vol. 1, NASA SP-270 pp 347-390.

Deal, P.L., Keyser, G.L., Fisher, B.D. and Crabill, N.L. 11-13 Nov. 1981
Thunderstorm hazards flight research program overview.
AIAA/SETP/SFTE/SAE 1st Flight Testing Conference, Las Vegas, Nevada.

Keyser, G.L., Deal, P.L., Fisher, B.D. & Crabill, N.L. Oct. 1980
Operational evaluation of thunderstorm penetration test flights during project storm hazards '80.
Proc. 18th Annual SAFE Symposium, San Diego Ca. Published 1981.

Rhyne, R.H., Murrow, H.N., and Sidwell, K. 1976
Atmospheric turbulence power spectral measurements to long wavelengths for several meteorological conditions.
pp 271-286 in NASA-SP-416.

Murrow, H.N. and Eckstrom, C.V. 1979
Drones for aerodynamic and structural testing (DAST) - A status report.
Journal of Aircraft Vol. 16 No. 8. Aug. 1979 pp 521-526

Perry, B., Kroll, R.I., Miller, R.D. and Goetz, R.C. 1980
DYLOFLEX: A computer program for flexible aircraft flight dynamic loads analyses with active controls.
Journal of Aircraft Vol. 17 No. 4 April 1980 pp 275-282.

9.4 Reports received from NSSL

Kessler, E. (Ed) 1981
Thunderstorms: A social, scientific and technological documentary.
Vol. 1: The thunderstorm in human affairs.
U.S. Dept. of Commerce.

Sasaki, Y.K. and Baxter, T. 1981
Storm outflow: The gust front
Unpublished draft of a chapter to be included in Volume 2 of the above work.

Kessler, E. 1977
National Severe Storms Laboratory:
History and F.Y. 1976 program.
NSSL Special report.

NSSL 1980
Annual report FY-80

Waldteufel, P.
An analysis of weather spectra variance in a tornadic storm.
NOAA Tech. Memo NOAA-TM-ERL-NSSL-76

Goff, R.C. 1975
Thunderstorm outflow kinematics and dynamics
NOAA Tech. Memo. NOAA-TM-ERL-NSSL-75

Doviak, R.J. and Berger, M. 1980
Turbulence and waves in the optically clear planetary boundary layer resolved by dual-Doppler radars.
Radio Science Vol. 15, No. 2 pp 297-317.

Reinking, R.F., Doviak, R.J. and Gilmer, R.O. 1981
Clear - Air roll vortices and turbulence motions as detected with an airborne gust probe and dual-Doppler radar.
Journal of Applied Meteorology, Vol. 20, No. 6 June 1981.

Crawford, K.C. and Hudson, H.R. 1970
Behaviour of winds in the lowest 1500 feet in central Oklahoma: June 1966 - May 1967.
ESSA Technical Memorandum ERLTM-NSSL-48.

Goff, R.C. and Zittel, D. 1974
The NSSL/WKY - TV Tower:
Data collection program April - July 1972
NOAA-TM-ERL-NSSL-68.

Carter, J.K. 1970
The meteorologically instrumented WKY-TV Tower facility.NOAA Technical Memorandum ERLTM-NSSL-50
NOAA Technical Memorandum ERLTM-NSSL-50.

Carter, J.K. 1970
The meteorologically instrumented WKY-TV Tower facility.
NOAA Technical Memorandum ERLTM-NSSL-50.

Lee, J.T. and Carpenter, D. 1979
1973-1977 Rough rider turbulence - radar intensity study
Report No. FAA-RD-78-115.

Lee, J.T. 1981
Doppler radar research and application to aviation flight safety, 1977-79.
Report No. DOT/FAA/RD - 81/79.

APPENDIX 1

LIST OF CONTACTS AND ADDRESSES

1. Dr. Joe Golden,
   ERL,
   3100 Marine Ave.,
   Boulder, Colorado 80302

2. Mr. Charles Jones,
   FAA - Office of International Aviation,
   800 Independence Ave. SW
   Washington, D.C. 20591

3. Mr. Norman Crabill,
   Mail Stop 247,
   NASA Langley Research Centre,
   Hampton, Virginia 23665

4. Mr. Jean Lee,
   NSSL,
   1313 Halley Circle,
   Norman, Oklahoma 73069

APPENDIX 2

12th A.M.S. CONFERENCE ON SEVERE LOCAL STORMS

LIST OF SESSIONS

1. Hail
2. Climatology
3. Forecasting
4. Storm Weather Relations
5. SESAME
6. Severe Storm Dynamics
7. Tornado Damage and Simulation
8. Pot pourri
9. Tornadoes
10. Radar
11. Warning and Preparedness
12. Satellite
13. Modelling
14. Mesoscale and Synoptic Scale Interactions

APPENDIX 3

12th Conference on Severe Local Storms, January 11-15, 1982, San Antonio, Texas.

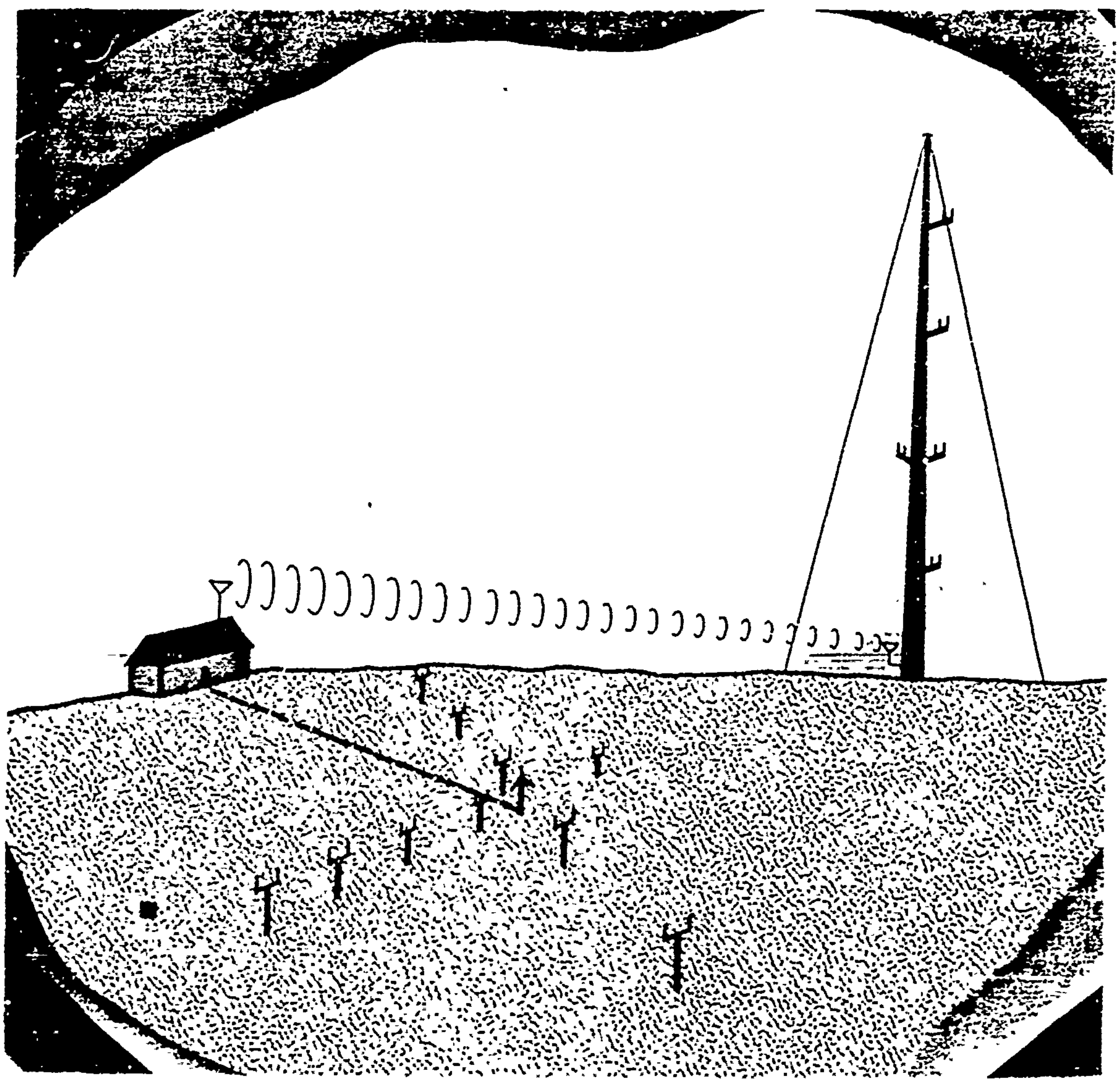
VERTICAL PROFILES OF WIND SPEED IN THUNDERSTORM GUST FRONTS

Douglas John Sherman
Aeronautical Research Laboratories
G.P.O. Box 4331, Melbourne, Australia.

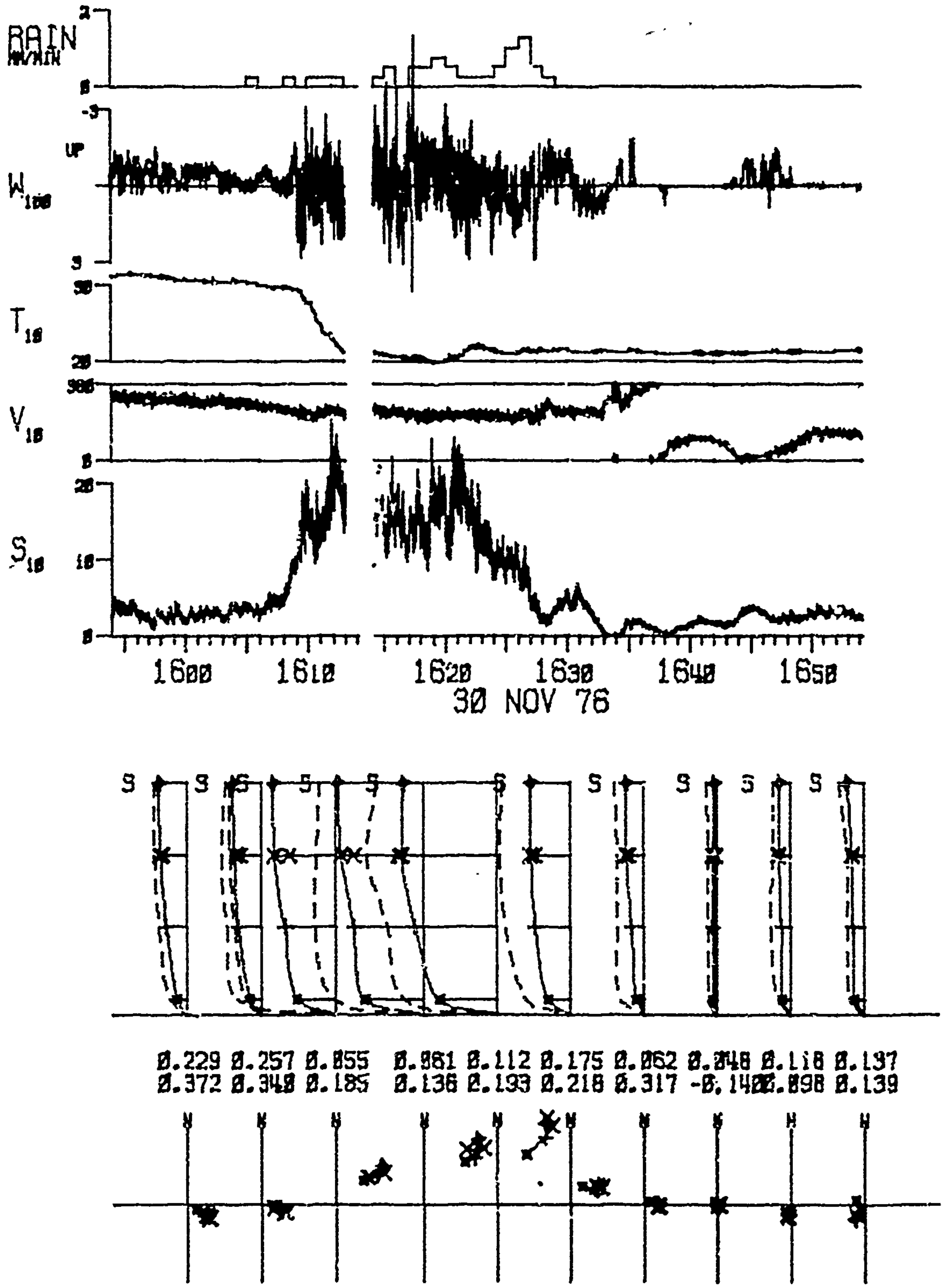
SUMMARY

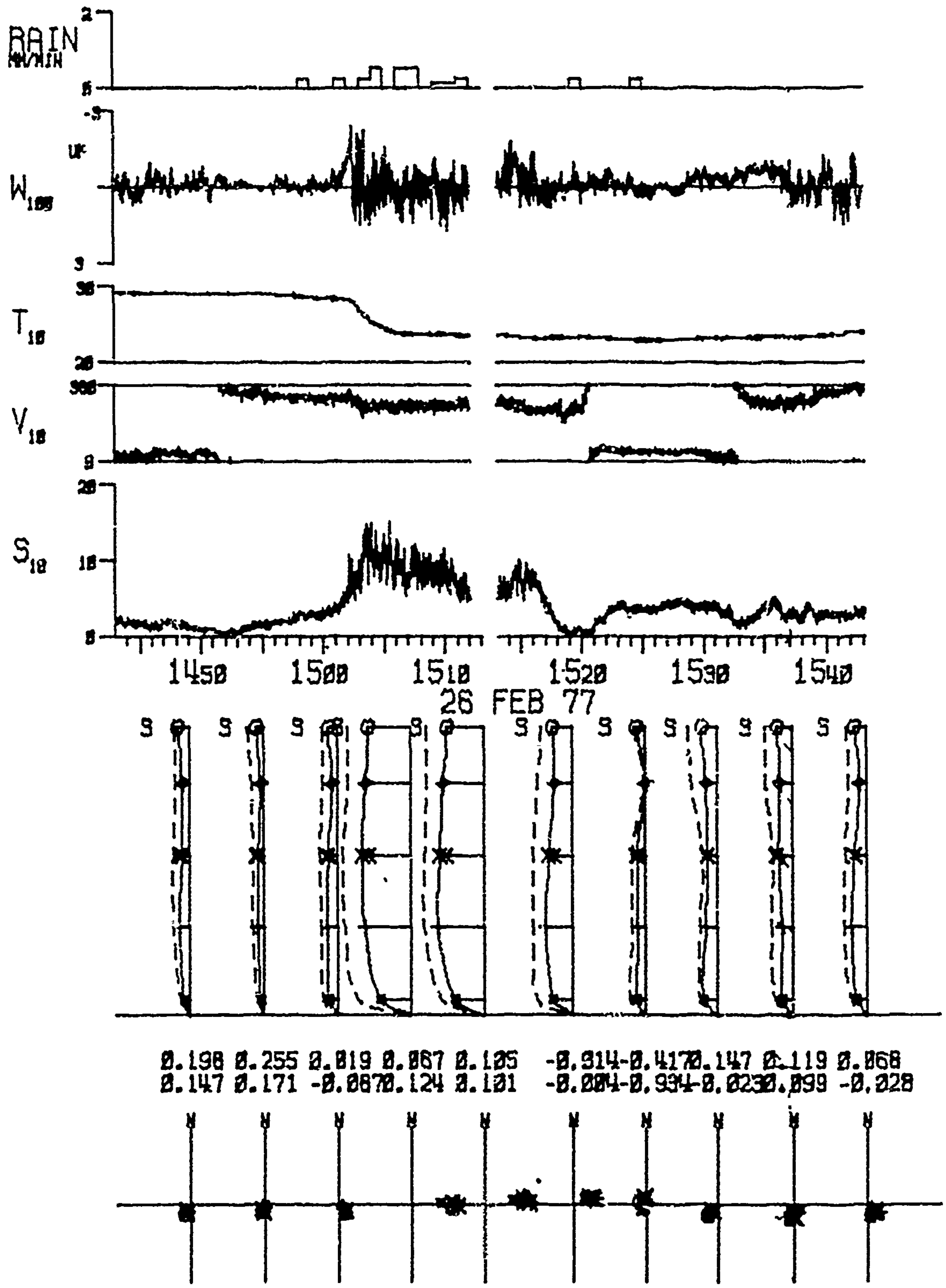
The vertical profile of maximum wind gust velocity is an important factor in the design of towers and other tall buildings. There are many parts of the world where design wind speed conditions occur predominantly in thunderstorm gust front situations, and since tank model experiments indicate the possibility of velocity profiles with maxima near the level of the gust front nose (rather than monotonically increasing wind speed with height) it is desirable to measure profiles of wind speed in actual gust fronts.

Using anemometers mounted on a 200 m, broadcasting tower at Brisbane, Australia, profiles of six minute mean velocity and peak three second gust during each six minute period have been obtained. About one third of the peak gust profiles obtained during the passage of thunderstorm gust fronts show maxima at about the 100 m. level, and these maxima have wind speeds about 10% greater than would be expected in a normal boundary layer profile with the given mean wind speed at the ten metre level.



Bald Hills is a suburb of Brisbane, Australia. Anemometers have been installed at 50m intervals on a 200m radio transmitting tower and in a 10m horizontal T array near the base of the tower. Data are recorded at 1 second intervals on magnetic tape.


RAIN
MM/MIN
W100
UP
T10
V10
S10
1600
1610
1620
1630
1640
1650
30 NOV 76
0.229 0.257 0.055 0.061 0.112 0.175 0.062 0.048 0.118 0.137
0.372 0.348 0.185 0.136 0.193 0.218 0.317 -0.140 0.098 0.139


RAIN
MM/MIN
W
T
V
S
1450 1500 1510 1520 1530 1540
26 FEB 77
0.198 0.255 0.019 0.067 0.105 -0.314-0.4170.147 0.119 0.068
0.147 0.171 -0.0670.124 0.101 -0.004-0.934-0.0230.099 -0.028

During the 1976-77 thunderstorm season seven gust front passages were observed at Bald Hills. Time histories of some of these are shown. The velocity profiles shown are profiles of

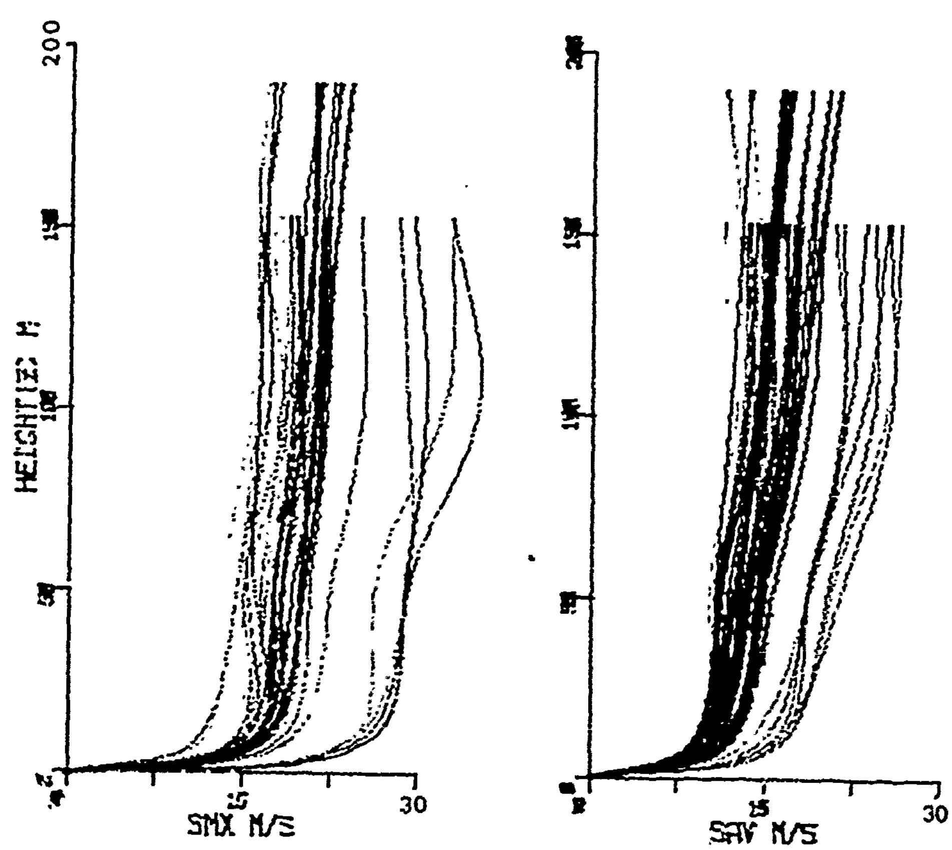
(a) 6 minute mean wind speed (solid line)

(b) 3 second peak gust observed during each six minute period (dotted line).

When design peak wind speeds occur in thunderstorm gust front situations the vertical velocity profiles may show maxima somewhere around the mid-depth of the density current outflow.

The problem of interest to structural engineers is whether the design wind profile should be taken as different from the power law or log law profile used to describe boundary layer winds.

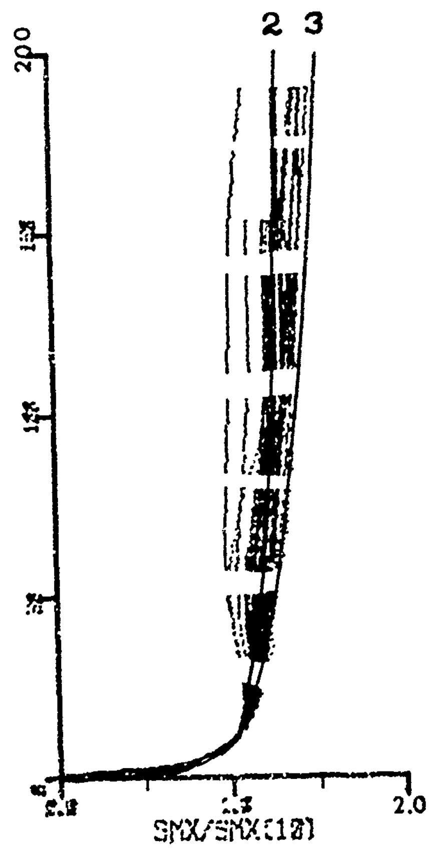
(The peak observed 10m gust of 26 m/s corresponds to a return period of about 4 years for the Brisbane area.)

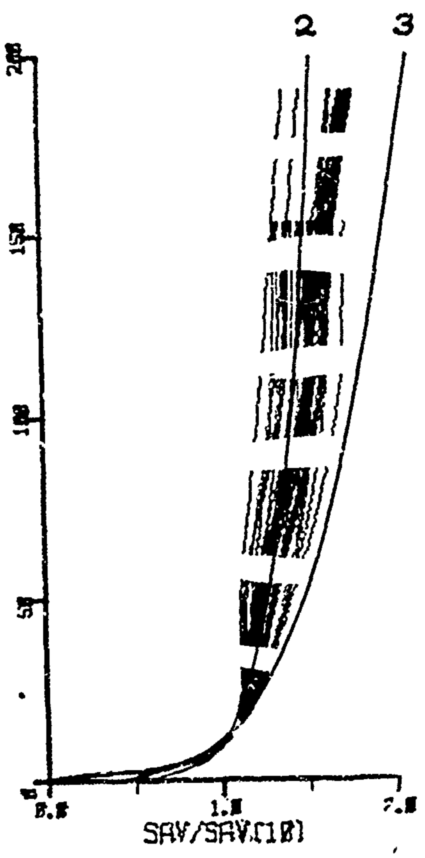


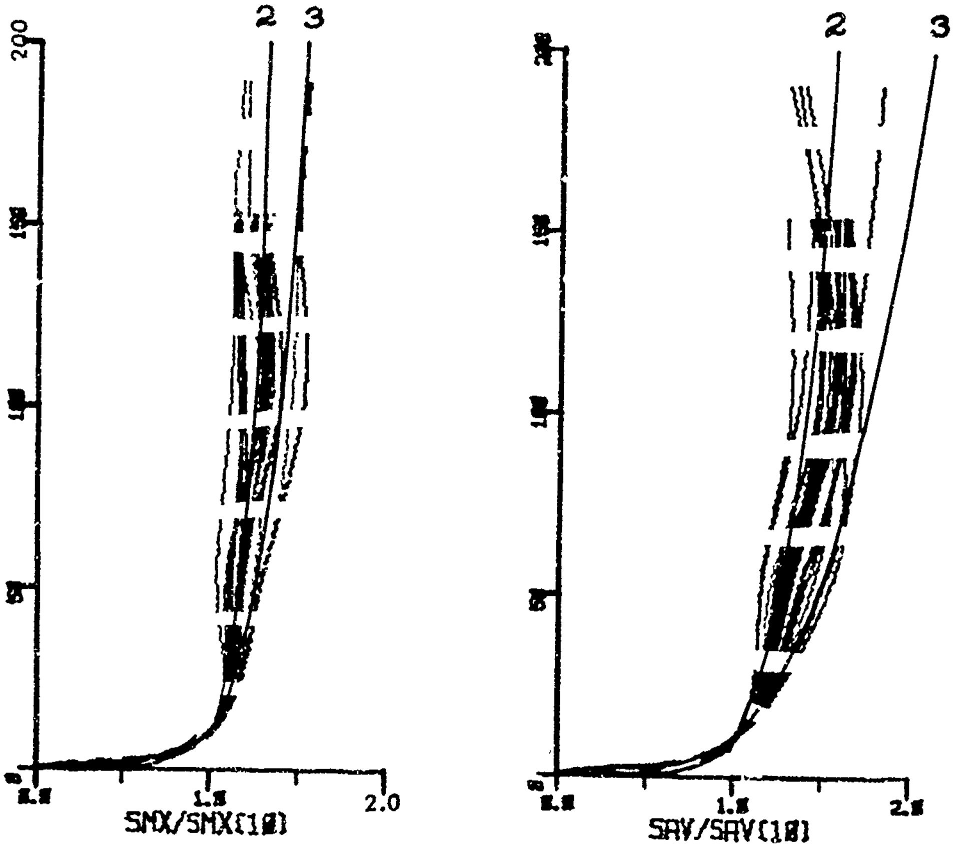
When all the stronger velocity profiles ($\bar{S}_{10} > 8.5$ m/s) are plotted together it may be seen that the strongest winds occur in profiles with maxima at the 100m level.

All cases when either the peak wind speed profile or the mean wind speed profile showed a maximum near the 100m level were plotted on one graph in a non-dimensional form (i.e. divided by the speed at the 10m level) and the remaining cases in a separate graph.

Overlays on these two figures show the design wind speed profile according to the Australian wind load code (see separate note) for terrain categories 2 and 3. (The Bald Hills site is intermediate between these two categories.)







The profiles which do not have maxima fall within the two design curves shown but some of the profiles with maxima exceed the design wind speed profile by up to 10% over the height range between 50m and 150m. This observation needs further checking, preferably with wind speed profiles obtained in more extreme cases.

Note Australian Code for Wind Loads on Buildings

This code specifies power law wind speed profiles for four terrain categories:

$$\frac{S_z}{S_{zg}} = \left(\frac{Z}{Z_g}\right)^k \quad \text{for 3-second peak gust}$$

$$\frac{\bar{S}_z}{\bar{S}_{zg}} = \left(\frac{Z}{Z_g}\right)^\alpha \quad \text{for mean velocity.}$$

Terrain Category	Z_g m	k	α	Corresponding value of Z_o for Log-Law mm
1. Exposed open terrain Few obstacles	250	0.07	0.11	2
2. Open terrain Scattered obstructions	300	0.09	0.15	20
3. Close spaced obstructions (suburban)	400	0.14	0.25	200
4. High close spaced obstructions (city centres)	500	0.20	0.36	2000

FIG. 1

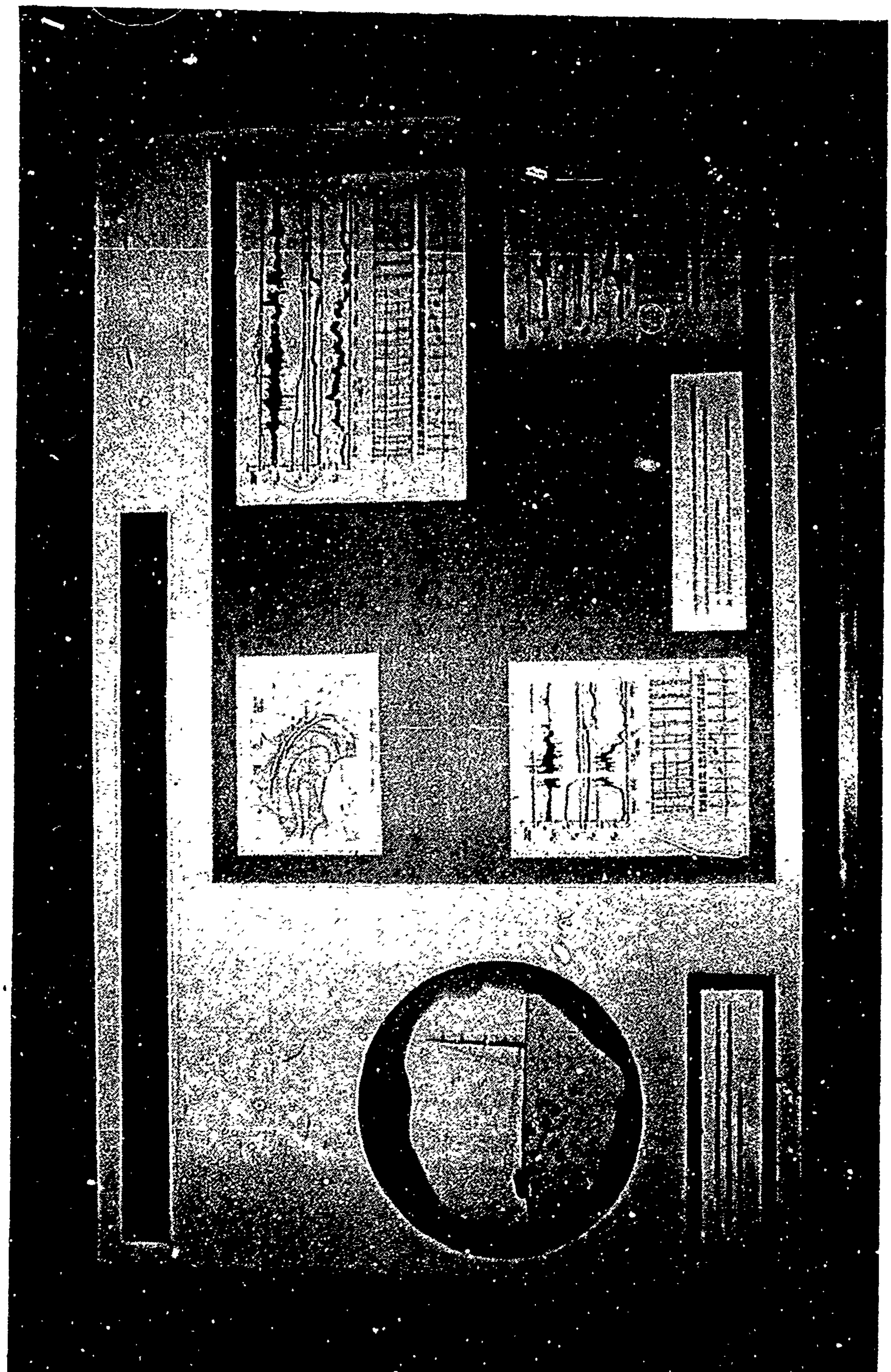
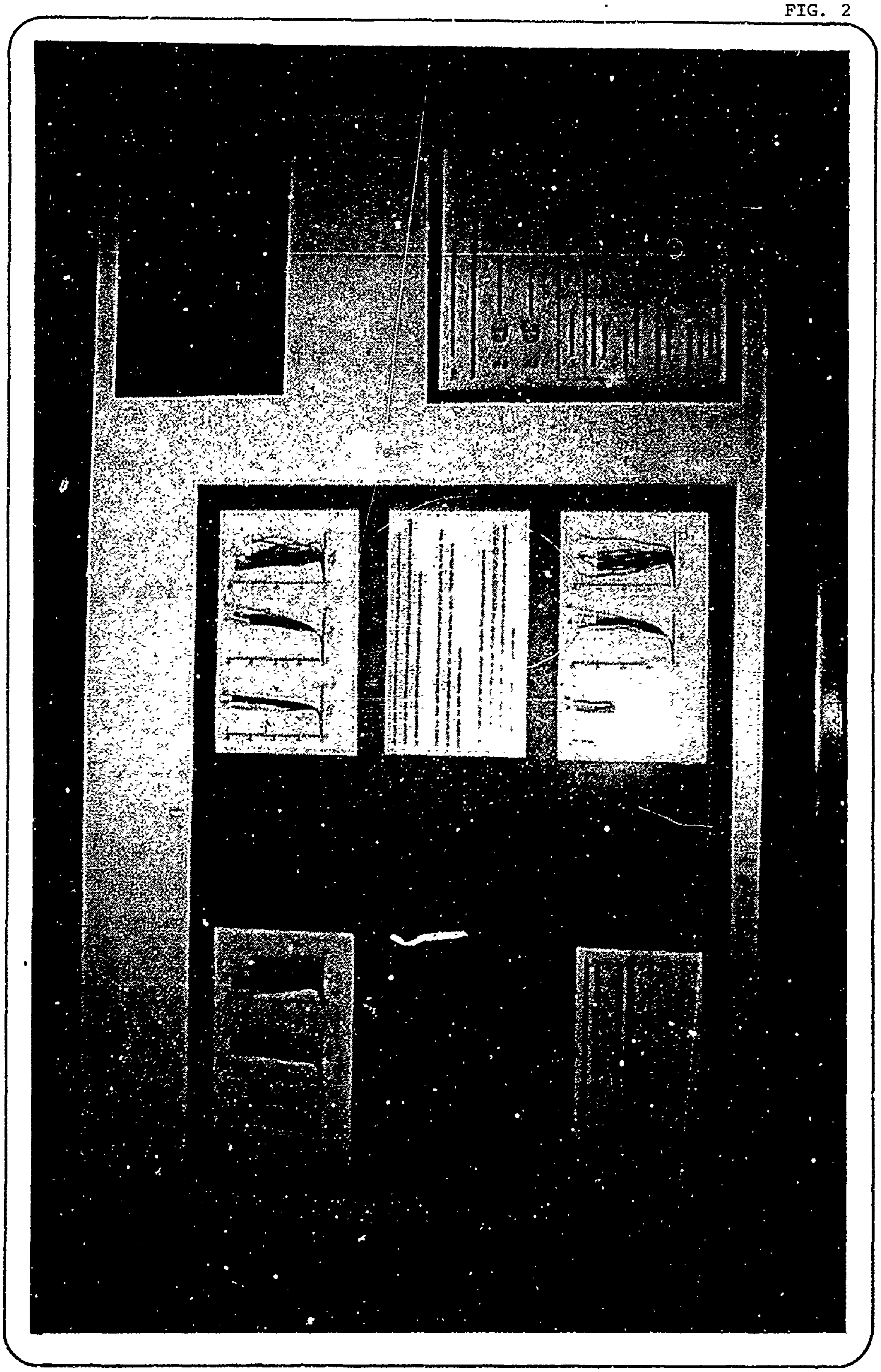


FIG. 2



NOTE:

Appendices 4 to 16 are on microfiche in an envelope at the back of this report. A very limited number of these appendices have also been produced and bound separately as a supplement to certain of the copies of this report.

DISTRIBUTION

AUSTRALIA

Department of Defence and Department of Defence Support

Central Office

Chief Defence Scientist)
Deputy Chief Defence Scientist) (1 copy)
Superintendent, Science and Technology Programmes)
Controller, Projects and Analytical Studies)
Director International Programmes
Defence Science Representative (U.K.) (Doc Data sheet only)
Counsellor, Defence Science (U.S.A.) (Doc Data sheet only)
Defence Central Library
Document Exchange Centre, D.I.S.B. (17 copies)
Joint Intelligence Organisation
Librarian H Block, Victoria Barracks, Melbourne
Director General - Army Development (NSO) (4 copies)

Aeronautical Research Laboratories

Chief Superintendent
Library
Superintendent - Structures
Divisional File - Structures
Author: Dr. D.J. Sherman (2 copies)
C.K. Rider
J.Y. Mann
G. Long
D.G. Ford
B.C. Hoskin
P. Farrell
J.M. Finney
D. Hatton
K.W. Anderson

Materials Research Laboratories

Chief Superintendent/Library

Defence Research Centre

Library

Central Studies Establishment

Information Centre

.../cont.

DISTRIBUTION (CONT.D)

Navy Office

Navy Scientific Adviser

Army Office

Army Scientific Adviser

Air Force Office

Air Force Scientific Adviser
Technical Division Library

Department of Science & Technology

Bureau of Meteorology, Library
R.R. Brook
P.A. Barclay

Department of Aviation

Library
Airworthiness Group
Mr. K.A. O'Brien

Monash University

Prof. B.R. Morton
Dr. R.K. Smith

CANADA

Dr. David Simpson, NRC

U.K.

Dr. Roy Maxwell, RAE

U.S.A.

Dr. John Goodman, USAF-ASD

SPARES (5 copies)

TOTAL (63 copies)

Department of Defence

DOCUMENT CONTROL DATA

1. a. AR No	1. b. Establishment No	2. Document Date	3. Task No
AR-002-899	ARL-STRUC-TECH-MEMO-344	August, 1982	DST 82/057

4. Title	5 Security	6. No Pages / 7. No Refs
REPORT ON A VISIT TO THE USA DURING JANUARY 1982 RELATING TO THE EFFECT OF TURBULENCE AND OTHER METEOROLOGICAL HAZARDS ON AIRCRAFT FLIGHT	a. document UNCLASSIFIED b. title U c. abstract U	6. No Pages 28 7. No Refs 37

8. Author(s)	9. Downgrading Instructions
SHERMAN, Douglas J.	–

10. Corporate Author and Address	11 Authority *(as appropriate)*
Aeronautical Research Laboratories. P.O. Box 4331, MELBOURNE, VIC. 3001	a.Sponsor b.Security c.Downgrading d.Approval –

12. Secondary Distribution *(of this document)*

Approved for Public Release.

Overseas enquirers outside stated limitations should be referred through ASDIS, Defence Information Services Branch, Department of Defence, Campbell Park, CANBERRA ACT 2601

13. a. This document may be ANNOUNCED in catalogues and awareness services available to ...

No limitations.

13. b. Citation for other purposes *(ie casual announcement)* may be ~~select~~ unrestricted ~~(or)~~ ~~as for 13 a.~~

14. Descriptors	15. COSATI Group
Visit reports Thunderstorms Clear air turbulence Aviation meteorology	0402

16. Abstract

In January 1982 the author visited the United States to attend and present a paper at the 12th Conference on Severe Local Storms in San Antonio, Texas. This report highlights certain aspects of that conference and details other discussions with the NOAA Environmental Research Laboratories, the FAA, the NASA Langley Research Centre and the National Severe Storms Laboratory.

This page is to be used to record information which is required by the Establishment for its own use but which will not be added to the DISTIS data base unless specifically requested.

16. Abstract *(Contd)*

17 Imprint

Aeronautical Research Laboratories, Melbourne.

18. Document Series and Number	19. Cost Code	20. Type of Report and Period Covered
Structures Technical Memorandum 344	24 7011	Visit report

21. Computer Programs Used

-

22. Establishment File Ref(s)

G5/179/201
M2/518